TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909

INCORPORATED 1930

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VOLUME XVIII
No. 9 — 1953

32 VICTORIA ST
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A Reflector Contour for Use With Tubular Light Sources

By R. W. STEVENS, B.Sc., M.S.I.A. *(Member)*

Summary

Street lighting lanterns incorporating tubular fluorescent lamps often have a reflector system whose design is derived from the properties of the parabola. Because of the large angle subtended by the lamp at the surface of the reflector, the provision of a peak luminous intensity in a direction 70-80 deg. from the vertical generally results in a large amount of light being reflected above the horizontal.

An alternative to the parabola as a basis for a reflector system is described which avoids this difficulty. A differential equation defining suitable contours is derived and a solution to this equation is given.

The application of curves defined by these equations to practical reflector systems is then discussed.

(1) Introduction

It has been demonstrated that the distribution of light from a street lighting lantern should be such that the luminous intensity rises steadily from an appreciable value at the downward vertical to a peak value at an angle between 70 deg. and 80 deg. from the vertical, the intensity then falling rapidly to negligible values for directions above the horizontal [1, 2].

Ever since the tubular fluorescent lamp was first used for street lighting it has been common practice to use a reflector light control system, and although nowadays refractor control is often used successfully the former system is still popular. Designs of reflector systems are generally derived from the properties of the parabola. The most important property is that any ray of light emitted by a hypothetical point source at the focus and incident on the reflector will always be reflected in a direction parallel to the axis of the parabola. If, however, a source of finite size is placed with its centre at the focus the beam of light will be divergent, the angle of divergence being equal to the angle subtended by the source at the reflector surface. Thus for sources such as the filament horizon lamp with a small cross-section, the divergence is small, but when a tubular fluorescent lamp is used in the reflector system of a street lighting lantern the cross-section does not even approximate to a point source, and considerable divergence occurs. This is illustrated in Fig. 1. It is for this reason that in many lanterns the luminous intensities in directions above the horizontal are considerably greater than one would wish. The contour described in the following section allows these intensities to be reduced without reducing the peak intensity.

(2) The Theory of the Contour

With a parabola the divergence can be controlled to a limited extent by displacing the lamp so that the focus, whilst within the cross-section of the source, no longer coincides with the centre of it. What is really wanted, however, is a reflector which will give diverging beams arranged so that the limiting edges of the beams lie in the same direction (Fig. 2). In other words the contour of the reflector should be such that a ray of light from the perimeter of the lamp, and not a focal point, will always be reflected in a given direction; it follows that light from the source will always be reflected to one side of this direction.

A mathematical expression for this curve may be derived in the following way.

The author was formerly with Siemens Electric Lamps and Supplies, Ltd., and is now with Metropolitan-Vickers Electrical Co., Ltd.

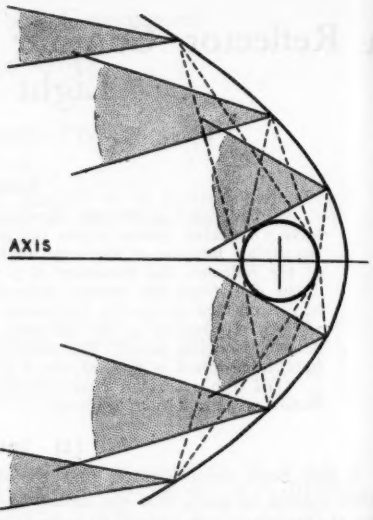


Fig. 1.

In Fig. 3 let the light source be represented by the circle with centre at O and of radius a. Let S be a point on the curve with co-ordinates (x,y) i.e., $x = NS$; $y = ON$.

Draw a line tangent to the circle at M and passing through S to represent a ray of light from the perimeter of the source. The line SR drawn parallel to the y axis will, by definition, represent the reflected ray. Produce SM to cut the y axis at T and draw a circle with centre T and of radius TS to cut the same axis at A and C. Join SC and draw the line AB passing through S.

Since $R\hat{S}B = T\hat{A}S = T\hat{S}A$ and the angle $A\hat{S}C$ is a right angle, $C\hat{S}T = C\hat{S}R$. This is in accord with the laws of reflection, and therefore SC is normal and AS is tangent to the curve. Now $C\hat{S}T + T\hat{S}A = 90$ deg., $O\hat{Q}A + O\hat{A}Q = 90$ deg. and $O\hat{A}Q = T\hat{S}A$; therefore $O\hat{Q}A = C\hat{S}T = \phi$. AS represents the slope of the curve, $\frac{dy}{dx}$, at S, and therefore $\frac{dy}{dx} = \tan \phi$.

Draw the line DG parallel to the y axis and touching the circle of radius a at E.

Then $$\tan \phi = \frac{GD}{DS} = \frac{DE+EF+FG}{DS}$$

or $$\frac{dy}{dx} = \frac{y+MF+FS}{x-a}$$

$$= \frac{y+\sqrt{x^2+y^2-a^2}}{x-a} \quad \ldots\ldots(1)$$

This equation may be solved directly for y, giving

$$y = \tfrac{1}{2}\left[x(p - \frac{1}{p}) - a(p + \frac{1}{p})\right] \quad \ldots\ldots(2)$$

where $p = \frac{dy}{dx} = \tan \phi$.

A solution in terms of x is

$$x = p(c - 2a\phi) - a \quad \ldots\ldots(3)$$

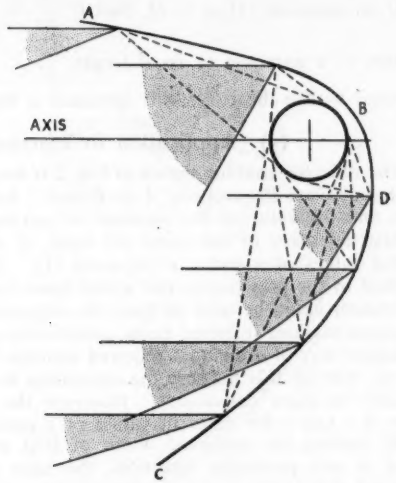


Fig. 2.

Thus the complete solution to equation (1) is the pair of parametric equations (2) and (3).

Fig. 4 shows typical curves defined by these equations. The y co-ordinate of the point on the curve where $\frac{dy}{dx} = O$ is $-\frac{C}{2}$, the value of x being $-a$. Therefore $\frac{C}{2}$ corresponds to the focal length of a parabolic reflector. It is also worth noting that when $\frac{dy}{dx} = 1$, $y = -a$ and $x = C - a(1 + \frac{\pi}{2})$.

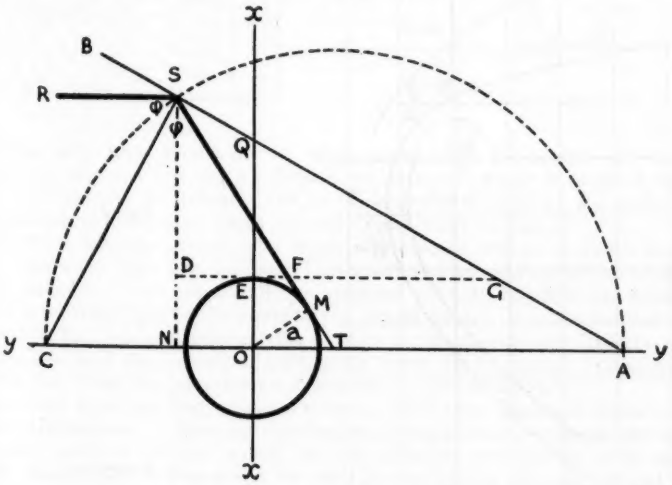


Fig. 3.

If, in equation (3), $a = O$, then $C\frac{dy}{dx} = x$ which gives $2Cy = x^2$, which is the equation to a parabola of focal length $\frac{C}{2}$. Alternatively as x and y become large compared with a the curve will approach a true parabolic form.

(3) Application to Practical Reflector Systems

The reflector contour shown in Fig. 2 is based on equations (2) and (3), which were used to calculate the sections A to B and C to D. A and C were taken as two fixed points and the value of the constant in equation (3) was found for each section. It was first necessary to determine the value of p at each point; this was done by substituting values of x and y in equation (1). Alternatively the geometric construction described in the previous section could have been used. It might be thought that this construction could be used to trace the required curve step by step, but unfortunately the approximations involved cause cumulative errors and the method is impracticable. An elegant way of drawing a required contour is to make use of a suitable differential analyser, but for this purpose the equivalent to equation (1) in polar co-ordinates will probably be more convenient. However the plotting of a contour by calculating values of x and y for different values of p presents no difficulties.

By finding the projected width of that portion of the reflector that would be flashed in any particular direction, the light distribution may be predicted. The calculated distribution for the reflector shown in Fig. 2 is the full curve in Fig. 5.

The equations defining the contour are precise and the theoretical geometric arrangement of the source and reflector must be closely followed in practice if the sharp cut-off is to be obtained. If approximations to the curve—for example, that formed by the step-by-step construction mentioned in the previous paragraph, or by segments

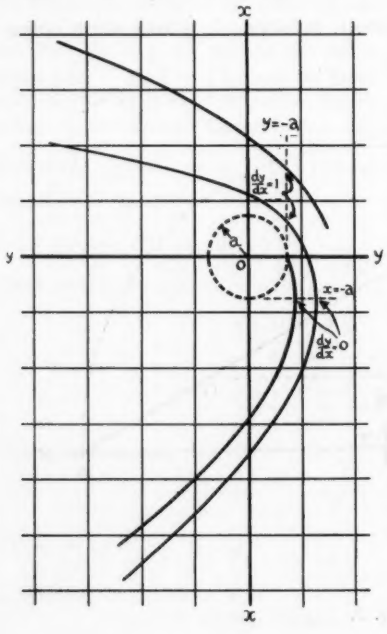
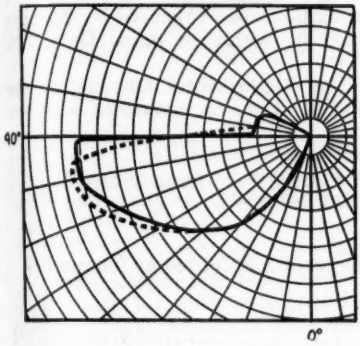


Fig. 4.



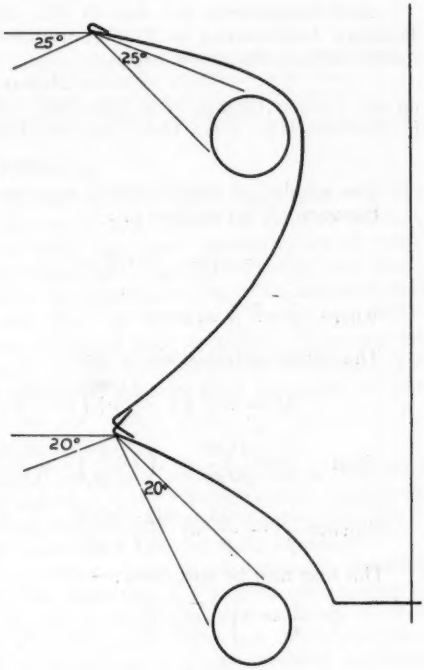
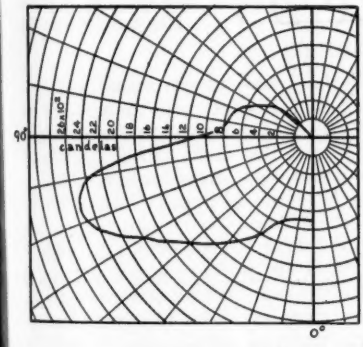


Fig. 5 (above).
Fig. 6 (right).
Fig. 7 (below).



of parabolas with focal points on the circle representing the source—are used, the cut-off quickly becomes less sharp. Even if the precise contour is adopted, unavoidable errors in forming the reflector and in the size and position of the source result in an experimental distribution more like the dotted curve in Fig. 5.

Half of the reflector system of a 4-lamp fluorescent lantern is shown in Fig. 6, and Fig. 7 shows its light distribution. The relatively high position of the upper lamp should be noticed. This can usually be arranged without difficulty and reduces the amount of bare lamp light emitted beyond the cut-off limit. If a low position relative to the upper reflector edge is unavoidable, as with the lower lamp, an auxiliary reflector may be used to limit the amount of light going above the horizontal, and because this light comes only from the lamp such a device can be very effective.

Apart from street lighting, reflector systems of the type described above may well have other applications. Thus the distribution shown in Fig. 5 suggests that a fitting incorporating such a reflector would be very suitable for lighting shop windows. Inside the shop similar fittings could be used for the lighting of counters and display shelves, whilst other applications might include the lighting of chalkboards or control boards.

Acknowledgments

The work described was carried out by the author when employed by Siemens Electric Lamps and Supplies, Ltd., London, and he wishes to thank Dr. J. N. Aldington for permission to publish this paper.

Acknowledgments are due to the staff of the Mathematical Division of the Research Laboratories of Elliott Brothers (London), Ltd., for assistance with the mathematical parts of the paper.

References

(1) B.S. Code of Practice. C.P. 1004 : 1952, "Street Lighting Pt. I. Traffic Routes."
(2) Waldram, J. M., Trans. Illum. Eng. Soc. (London), **12**, 167 (1947).

Appendix

The solution of the differential equation in terms of x is derived as follows :— Equation (2) is rewritten as :—

$$2y = x\left(p-\frac{1}{p}\right)-a\left(p+\frac{1}{p}\right) \quad \ldots\ldots(4)$$

where $p = \frac{dy}{dx} = \tan\phi$

This is now differentiated to give

$$2p = x\frac{dp}{dx}\left(1+\frac{1}{p^2}\right)+\left(p-\frac{1}{p}\right)-a\frac{dp}{dx}\left(1-\frac{1}{p^2}\right)$$

Then $$\left(p+\frac{1}{p}\right)\frac{dx}{dp} = x\left(1+\frac{1}{p^2}\right)-a\left(1-\frac{1}{p^2}\right)$$

Whence $$\frac{dx}{p}-\frac{xdp}{p^2} = \frac{a(1-p^2)dp}{p^2(1+p^2)}$$

This may now be integrated :—

$$\frac{x}{p} = a\int\frac{1-p^2}{1+p^2}\frac{dp}{p^2}$$

$$\frac{x}{p} = -\frac{a}{p}-2a\tan^{-1}p+C \quad \ldots\ldots(5)$$

or $$x = p(c-2a\phi)-a$$

To find the significance of C, let $p \rightarrow o$. Then equation (5) becomes

$$x = Cp-a$$

since $\tan^{-1}p \rightarrow p$ and p^2 is of the second order of smallness. Substituting for x in equation (4) gives

$$2y=(Cp-a)\left(p-\frac{1}{p}\right)-a\left(p+\frac{1}{p}\right)$$

Neglecting second orders of p we have

$$y = -\frac{C}{2}$$

If $\frac{dy}{dx} = O$ in equation (5) then $x = -a$

If $\frac{dy}{dx} = I$ in equation (4) then $y = -a$ and in equation (5)

$$x = C-a\left(1+\frac{\pi}{2}\right)$$

A Survey of Vehicle Headlights

By V. J. JEHU, M.Sc., A.Inst.P.

Summary

A survey of the condition of vehicle headlights was made in the spring of 1952 on a sample of cars and commercial vehicles. Both the alignment and the intensity of the light beams were examined. The results are given, and their bearing on the problem of dazzle is discussed.

(1) Introduction

Observations have shown that much of the dazzle which is experienced on our roads at night is caused by the great differences which exist between the lights on different vehicles. These differences arise in various ways: the lamps themselves are of many different designs, many have deteriorated considerably since they were first fitted, some are out of focus, some are not aimed with a sufficient degree of accuracy, and the vehicles on which they are mounted alter their tilt with every change of loading.

To obtain information about the extent of some of these differences, measurements of aim and beam intensity have been made on the headlamps and passlamps of a sample of cars and commercial vehicles chosen at random from the traffic on one of our main roads.

(2) Description of Survey

The measurements were made in daylight on a concrete lay-by on the A40 road at Cassington, near Oxford, during April and May, 1952. Vehicles were stopped by a police officer who asked drivers to co-operate by submitting their vehicles for a headlamp check; about 400 cars and 400 commercial vehicles were examined.

The measurements were made with a commercial beam setter specially modified to facilitate this kind of testing (Fig. 1). The apparatus was aligned with respect to the vehicle under test by means of a jig resting on the ground and consisting of four lengths of aluminium bar jointed to form a parallelogram. One side of the parallelogram was pressed against the front tyres of the vehicle, and the wheels of the beam setter were then brought into contact with the other side. In this way the axis of the optical system of the beam setter was quickly aligned parallel to the longitudinal axis of the vehicle. There is a certain error in thus assuming that the front wheels define the axis of the vehicle, but most other ways of finding this axis are also subject to error or are extremely tedious and time-consuming. The optical axis of the instrument was kept parallel with the ground and, by means of a viewing screen graduated in degrees, the aim of the headlamp was estimated visually to the nearest 0.5 deg., both in the horizontal and vertical directions. The horizontal intensity of the headlight beams was then measured by means of the photo-electric cell mounted at the centre of the viewing screen of the beam setter, low intensities being measured on a separate scale giving a full-scale deflection for 10,000 candelas. Another condenser lens, photocell and meter assembly, light enough to be carried by the operator, was used to measure the maximum intensity of the meeting beam.* The meters were checked periodically against a standard headlamp. While the measurements of intensity were being made the engine of the vehicle was either stopped or idling. Besides the aim and intensities and other details of the lamps fitted on the vehicles, particulars

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* The terms "driving beam" and "meeting beam" are adopted instead of the more widely used, but somewhat ambiguous terms, "main beam" and "dipped beam." Any beam which remained on or could be switched on while the offside headlight was switched off or dipped was regarded as a "meeting" beam. It is not known that all these beams, especially those from foglamps or passlamps, were in fact used when meeting other vehicles. Experience suggests that a high proportion of them are often used in this way.

Fig. 1. Beam-testing equipment in use.

were noted of the vehicles themselves, including the state of loading of commercial vehicles.

The results are summarised in Figs. 2 and 3 and in Tables 1-6. They include the statistical distributions obtained for vertical aim, horizontal aim, horizontal intensity of the meeting beams, horizontal intensity of the driving beams and maximum intensity of the meeting beams from lamps which were, or which could be, used to supply the meeting beam. In analysing the measurements of aim it is necessary to group the results according to the type of beam. Double-beam lamps, that is, those emitting both a driving beam and a meeting beam, were grouped with the lamps emitting only a driving beam, and the aim of the meeting beam was not measured.

(3) Discussion of Results

(3.1) Aim

In Great Britain there are no regulations specifying the dip or deflection of headlamp or passlamp beams. It is generally agreed that the driving beam on a car should be aimed straight ahead with perhaps a dip of about 0.5 deg. to allow for an upward tilt when the vehicle is fully loaded. There is less unanimity over the aim of passlamps, or other lamps giving only a meeting beam, but in double-beam lamps the practice usually adopted by the manufacturers in this country is to dip the meeting beam at least 3 deg. in relation to the driving beam and deflect it to the left. For convenience in discussing the results in this paper it will be assumed that the "correct" aim for a driving beam is straight ahead with an angle of dip of 0.5 deg. If the lamp also gives a meeting beam the aim of the latter is fixed by the manufacturer. For lamps giving only a meeting beam it will be assumed that the "correct" angle of dip is 3 deg.

Table 1.

Vertical and Horizontal Aim of Driving Beams of Headlamps

Vehicle		Lamp mounting	Number of lamps	Percentage of headlamps									
				With aim within the following limits of ½ deg. down and straight ahead						With aim outside ±3deg. from ½deg. down and straight ahead	With wide beams	With diffuse beams	Not working
Type	Age			±½ deg.	±1 deg.	±1½ deg.	±2 deg.	±2½ deg.	±3 deg.				
Cars	Pre-war	Mostly stem	313	6	15	24	33	42	51	21	2	19	7
	Post-war	Stem	178	5	12	21	36	50	60	16	2	16	6
	Post-war	Flush	180	17	41	62	75	83	89	7	0	1	3
	Unknown	Mostly stem	56	7	18	37	51	60	66	19	0	13	2
	All cars	Stem and flush	727	9	20	33	45	54	62	19	1	13	5
Vans	All vans	Stem and flush	110	4	15	30	42	51	57	18	3	14	8
Lorries	Pre-war	Stem	57	2	5	11	18	26	29	22	5	28	16
	Wartime	Stem	39	6	13	20	29	39	45	14	8	20	13
	Post-war	Stem	292	4	11	19	27	34	40	33	8	13	6
	Post-war	Flush	98	10	26	45	61	75	85	11	1	1	2
	Unknown	Mostly stem	29	2	6	13	20	26	31	34	7	21	7
	All lorries	Stem and flush	515	5	14	23	32	41	48	26	6	13	7

Assumption of a " correct " sideway deflection has not been made since meeting beams, especially those from passlamps, vary greatly in width.

Of the lamps examined a number did not work, and a larger number produced beams so diffuse that it was impossible to locate the maximum intensity and so determine the aim. Table 1 gives a complete analysis for lamps emitting a driving beam; about 6 per cent. did not work, and about 13 per cent. were diffuse. Lamps for which no readings could be obtained have been omitted from the analyses given in Tables 2-6 and in Figs. 2 and 3.

All the tables and figures show that there is an extremely wide scatter in the measurements. It is not so much that there is a clearly marked tendency for the lamps to be incorrectly aimed as that the standard of aiming is poor.

Table 1 shows that only 9 per cent. of the driving beams on cars, 4 per cent. on vans and 5 per cent. on lorries were within 0.5 deg., horizontally and vertically, of the " correct " aim. Beams aimed more than 3 deg. from the " correct " position, diffuse beams, or defective lamps accounted for about 40 per cent. of the beams on cars or vans, and 50 per cent. on lorries.

Misaim in a vertical direction is more important than horizontal misaim, since the intensity changes more rapidly in the vertical direction. Fig. 2 and Table 2 show that the driving beams are on the average aimed too low especially on commercial

Table 2.

Variation of Vertical Aim of Lamps

	Type of beam	Mounting	Mean aim	Standard deviation σ* of aim about mean
Cars	Driving beams	Stem	0.7 deg. down	1.9 deg.
		Flush	0.7 deg. down	1.1 deg.
		All	0.7 deg. down	1.7 deg.
	Meeting beams from single-beam headlamps and passlamps	Stem	1.1 deg. down	2.6 deg.

	Type of beam	Load	Mean aim	Standard deviation σ* of aim about mean
Commercial vehicles	Driving beams	No load	1.5 deg. down	2.2 deg.
		Full load	0.6 deg. down	2.0 deg.
	Meeting beams from single-beam headlamps and passlamps	No load	2.5 deg. down	3.2 deg.
		Full load	1.8 deg. down	2.7 deg.

* In a large number of tests, the percentage of results expected to be outside certain ranges about the mean aim are as follows :—

Limits of deviation from mean aim	$\pm 2\sigma$	$\pm 1.6\sigma$	$\pm 1.3\sigma$	$\pm 0.67\sigma$
Approximate percentage of results outside these limits	5	10	20	50

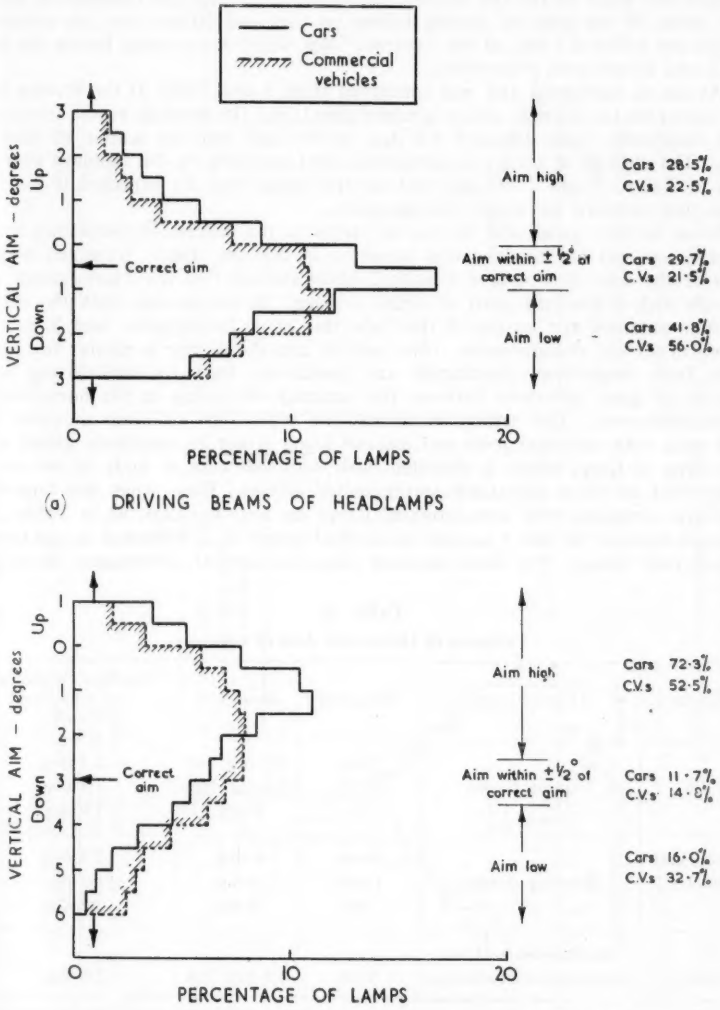

Fig. 2. The distribution of vertical aim within about 3 deg. of "correct" aim. (Diffuse beams omitted from sample.)

vehicles (vans and lorries), but that the meeting beams from single-beam lamps are in general aimed much too high, the average dip being only about 1 deg. for cars, substantially the same as for the driving beam, and 2-2.5 deg. for commercial vehicles. Only about 30 per cent. of driving beams on cars and 20 per cent. on commercial vehicles are within 0.5 deg. of the "correct" dip, whilst for meeting beams the figures are 12 and 15 per cent. respectively.

As far as horizontal aim was concerned (Fig. 3 and Table 3) the driving beams were aimed on the average almost straight ahead, and the meeting beams from single-beam headlamps were deflected 1.5 deg. to the left, but the scatter of both was large. The amount of scatter is represented most concisely by the standard deviations given in Tables 2 and 3; 95 per cent. of the lamps may be expected to be aimed within two standard deviations of the mean.

Some of this scatter will be due to errors in the process of estimating the aim of the beam and not to an actual variation in the aim itself. Repeated measurements of the aim of a modern headlight beam showed that the measurement could be made with a standard error of about 0.3 deg. In comparison with the standard deviation obtained for beams of this type this error is negligible and it has been ignored in all the measurements. For vertical aim the scatter is greater for meeting beams from single-beam headlamps and passlamps, than for the driving beams. There is no great difference between the accuracy of aiming in the horizontal and vertical directions. The results show that the older type of lamp mounted on a single stem with universal joint and locknut fixing is not as accurately aimed as the newer type of lamp, which is mounted flush with the wing or body of the car and is supported on three adjustable spring-loaded screws. Even when the flush-fitting lamps are compared with stem-mounted lamps on post-war cars, as in Table 1, the difference remains, so that it cannot be ascribed merely to a difference in age between old and new lamps. The flush-mounted lamp has several advantages; its aim can

Table 3.

Variation of Horizontal Aim of Lamps

Vehicles	Type of beam	Mounting	Mean aim	Standard deviation σ* of aim about mean
Cars	Driving beams	Stem	0.1 deg. left	2.1 deg.
		Flush	0.2 deg. right	1.4 deg.
		All	0 deg.	1.9 deg.
Commercial vehicles	Driving beams	Stem	0 deg.	2.8 deg.
		Flush	0 deg.	1.4 deg.
		All	0 deg.	2.5 deg.
All vehicles	Meeting beams from single-beam headlamps	Stem	1.5 deg. left	2.6 deg.

* In a large number of tests, the percentage of results expected to be outside certain ranges about the mean aim are as follows :—

Limits of deviation from mean aim	$\pm 2\sigma$	$\pm 1.6\sigma$	$\pm 1.3\sigma$	$\pm 0.67\sigma$
Approximate percentage of results outside these limits	5	10	20	50

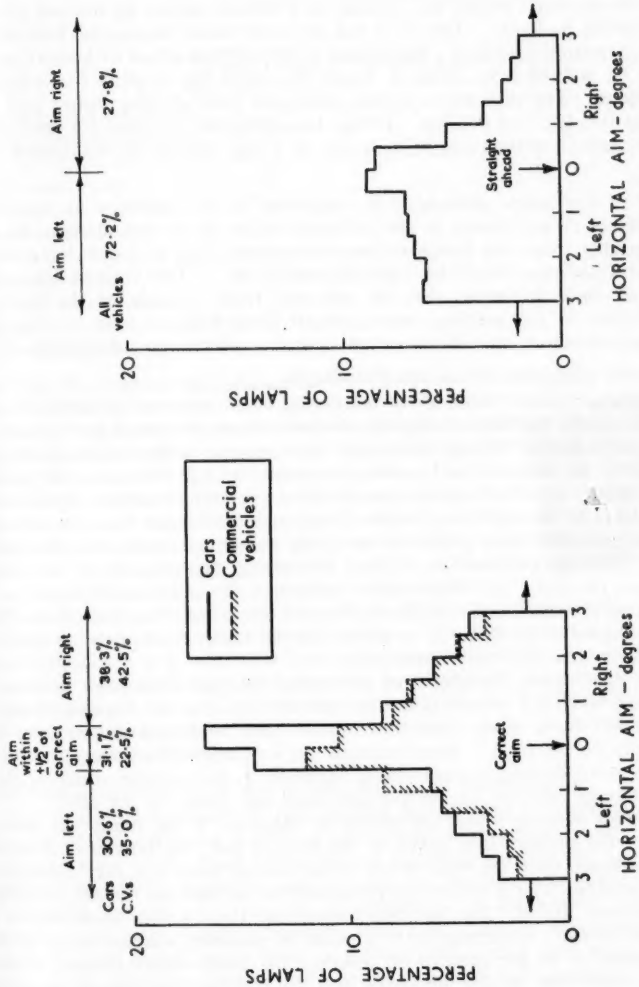

Fig. 3. The distribution of horizontal aim within 3 deg. of straight ahead.
(Diffuse beams omitted from sample.)

be adjusted smoothly and easily, it is less easily displaced, and if displaced it returns to its original position, and there is no danger of it changing its position while locking nuts are being tightened. There are strong reasons therefore, now supported by statistics obtained during actual use, for abandoning the stem mounting in favour of a method akin to that used in flush-mounted lamps.

As has already been stated, the loading of a vehicle affects its tilt and therefore the vertical aim of its lights. Tilts of 2 deg. or more occur during the normal loading of some commercial vehicles. Some idea of the average effect of loading on such vehicles may be derived from Table 2, where the mean dip is given for loaded and unloaded vehicles. The differences shown, estimated from driving beams and meeting beams, are 0.9 deg. and 0.7 deg. Unless headlights are adjusted for each change of load, differences in vertical aim of the order of 1 deg. will not be eliminated.

(3.2) Intensities

The aim of the lamp, although very important in its influence on dazzle and the light available to the driver, is not the only factor to be considered. Its effect will vary somewhat from one design of lamp to another, and in a new lamp may be quite different from one which has deteriorated badly. The clearest idea of the resultant of all these influences may be obtained from a study of the horizontal forward intensities of the meeting beams, whilst deterioration alone is most easily observed in the measurements of maximum intensity, which are independent of aim.

(3.2.1) *Horizontal Intensities, Glare and Illumination*

The horizontal forward intensity of a meeting beam gives an indication both of the intensity available for illuminating the road or objects ahead of the vehicle, and also of the glare intensity. Except for beams that are very badly misaimed, the glare intensity, which is the same as the horizontal intensity at large distances, will decrease somewhat as vehicles approach one another, whilst the intensity available for illuminating anything ahead of the vehicle and below lamp height will range from the horizontal intensity to the generally much greater value of the maximum intensity of the meeting beam. If the beam has become very diffuse, because of deterioration of the reflector or other causes, the glare and illumination intensities are substantially equal to the horizontal intensity because the beneficial effect of the cut-off has been lost. When the maximum intensity recorded was as low as 200 cd there was usually no difference between maximum and horizontal intensities.

As already mentioned, the engine of the vehicle had generally been switched off or was just idling when the measurements of intensity were made. Because of this the recorded intensities were lower than they would have been had the vehicles been running normally on the road. Measurements on a number of vehicles at the Road Research Laboratory showed a considerable variation in the increase which might be expected on different vehicles, but an average value was about 50 per cent.

The results for meeting beams are shown in Table 4. If the beam was obtained from two lamps the intensity was taken as the sum of the two individual intensities. As was to be expected from the wide errors in the aiming, there is a very considerable range in the intensities, and a very large proportion of all but the newest flush-fitting lamps give less than 500 cd. The last two columns in Table 4 give some idea of the disproportion in intensity occurring in 10 per cent. of meetings between lamps of each type. For example, in 10 per cent. of all meetings for double-beam lamps, i.e., those between the 22.4 per cent. having the lowest and the 22.4 per cent. having the highest intensities, one vehicle will have a horizontal intensity less than 450 cd and the other greater than 1850 cd.

The horizontal intensity in the meeting beams from double-beam lamps is generally less than in the beams from single-beam lamps, as was to be expected from the fact that the double-beam lamps, aimed by means of the driving beam, are much better

Table 4.
Horizontal Intensities of Meeting Beams

Type of lamp	Percentage of beams having an intensity in candelas greater than :							Intensity limits	
	500	1,000	2,000	3,000	4,000	5,000	8,000	Lowest 22.4 per cent. less than	Highest 22.4 per cent. greater than
All double-beam headlamps	75	49	20	10	6	4	2	450	1,850
All single-beam headlamps	74	57	38	26	18	12	5	400	3,400
Double-beam lamps									
Flush-fitting	91	70	26	13	8	5	1	850	2,200
Stem-mounted	69	40	17	9	5	4	2	350	1,600
Passlamps on cars	70	56	38	26	18	11	3	350	3,400
Passlamps on commercial vehicles	70	48	24	12	6	3	1	350	2,050

aimed than the single-beam lamps, which are generally set too high. Since only about 10 per cent. of the cars examined had single-beam lamps on the nearside, compared with nearly 50 per cent. of the commercial vehicles, it would be expected that for this reason alone the meeting beams from headlights on commercial vehicles would be found to be more dazzling than those on cars. This had already been observed in visual surveys carried out by the Laboratory. These surveys also showed that passlamps on cars and vans (classed together because of the difficulty of distinguishing between them at night) were more dazzling than those on lorries, a conclusion which is supported by the intensity figures in Table 4, when it is remembered that 85 per cent. of the commercial vehicles examined were lorries.

The superiority of the flush-fitting lamps, which has already been noted in regard to aiming, is confirmed by the intensity figures. The flush-fitting lamps have a higher average intensity but a somewhat narrower range with fewer very high or very low values, when compared with stem-mounted headlamps of the same kind. The ratio of intensities in 10 per cent. of encounters exceeds 2.6 for the flush-fitting lamps, and 4.6 for the stem-mounted lamps. There is, however, room for considerable improvement in both types of lamp.

(3.2.2) *Maximum Intensity of the Meeting Beam and Deterioration*

The maximum intensity of the meeting beam from a single lamp gives some indication of the extent to which its performance has deteriorated. Unfortunately the interpretation of the results is somewhat uncertain because the original maximum intensity is frequently unknown, and because an observed low value may be due to bad focusing as well as to a true deterioration of the system. High maximum intensities were more common formerly than now, and the maximum intensity of a properly focused pencil beam from a pre-war lamp may well exceed that from a post-war lamp, even though the post-war lamp is in better condition. However, the maximum intensities for meeting beams from headlights were probably originally all in excess of 10,000 cd, and intensities much lower than this indicate serious deterioration of one form or another. Passlamps have frequently been designed to have wide beams with maximum intensities less than 10,000 cd; the results for these have therefore been analysed separately in Table 5. Once again the range of intensities is very large.

Table 5.
Maximum Intensities of Lamps which Contribute to the Meeting Beam

Type of lamp	Percentage of lamps having an intensity in candelas greater than :							
	1,000	2,000	5,000	10,000	15,000	20,000	25,000	30,000
Headlamps	89	82	61	32	17	7	3	2
Passlamps	90	80	51	20	10	6	3	2

Table 6.
Horizontal Intensities of Driving Beams

Type of Vehicle	Percentage of beams having an intensity in candelas greater than :							
	1,000	2,000	5,000	10,000	15,000	20,000	25,000	30,000
Cars	90	81	60	38	26	17	11	7
Commercial vehicles	88	77	51	30	19	11	6	3

Some 10 per cent. of headlamps have maximum intensities in the meeting beam of less than 1,000 cd, certainly less than one-tenth of their initial intensity, indicating the seriousness of the deterioration.

(3.2.3) *Horizontal Intensity of the Driving Beam*

It is not so essential that the driving beam should be the same on all vehicles, since these beams should play no part in the production of glare if drivers dip their headlamps when they should. Nevertheless it is desirable that the driving beam of a vehicle should not be so feeble that the vehicle cannot be driven safely at an average speed. Table 6, which gives the horizontal intensities in the driving beams, shows that about 10 per cent. have intensities less than 1,000 cd and 40 or 50 per cent. less than 5,000 cd. An intensity of 5,000 cd has been found at the Road Research Laboratory to reveal a dark object at a distance of little over 100 ft. at a speed of 30 m.p.h. Such beams are inadequate for fast driving.

(3.3) Common Headlamp Faults

Table 1 shows that the beam patterns of no less than 13 per cent. of the driving beams were so diffuse that no estimate of aim was possible. Nearly all these were from stem-mounted lamps.

Most of the lamps that still employ stem mounting are so constructed that it is possible to alter the filament position with respect to the focus of the reflector, the intention being that differences in filament position between one bulb and another can be compensated in part by the adjustment provided. Table 1 shows that even among post-war vehicles diffuse beams are largely confined to the stem-mounted lamps. This supports the view that diffuse beams are often produced by incorrect positioning of the filament in the reflector, with the result that the beam from the lamp is defocused. No focusing adjustment is provided in flush-fitting headlamps, since the bulbs are made to much closer tolerances; only about 1 per cent. of the beams from the flush-fitting headlamps examined were found to be diffuse.

The second most common fault was failure of the dipping system. This could

generally be traced either to a burnt-out filament or to a faulty solenoid-operated dipping mechanism. Almost all the cars using single-beam nearside lamps (10 per cent. of the total) had faulty dipping systems.

Another possible fault with the lamp that can be focused is incorrect fitting of the bulb, with the result that the meeting beam from the lamp is aimed above the driving beam instead of below it. This occurred on 4 per cent. of the vehicles fitted with stem-mounted lamps; in some cases where two double-beam focusing headlamps were used, the beam from one lamp was elevated when that from the other lamp was depressed.

(3.4) Conclusions

The survey shows that:—

(i) There were considerable variations in both the horizontal and the vertical aiming of the lamps, the standard deviations being approximately 2 deg. for the driving beams and 2½ deg. for the meeting beams from single-beam lamps.

(ii) Whilst the proportion of the driving beams that were aimed within ± ½ deg. of a specified correct aim either in the vertical or in the horizontal direction was about 30 per cent. for the lamps on cars and 20 per cent. for the lamps on commercial vehicles, only 9 per cent. of the beams on cars and 5 per cent. of those on commercial vehicles were aimed within these limits in both the vertical and the horizontal directions.

(iii) The aim of flush-fitting headlamps was much better than that of other types of lamp.

(iv) Almost 13 per cent. of the driving beams were so diffuse, because of deterioration or defocusing, that no estimate of aim could be made, whilst about 6 per cent. of the lamps did not work.

(v) Measurements of the intensity in the horizontal plane of the meeting beams showed that (a) the proportion having a high-horizontal intensity, i.e., the proportion likely to cause dazzle, was greater for single-beam than for double-beam headlamps, and for passlamps on cars than for passlamps on commercial vehicles, and (b) flush-fitting lamps were, on the average, superior to other types of lamp in that few of them gave either a very low or a high horizontal intensity, implying that they provided better direct seeing and less tendency to cause dazzle.

(vi) The maximum intensity of about 10 per cent. of the meeting beams from individual headlamps was less than 1000 cd, indicating that a very considerable deterioration had occurred.

(vii) About 40 per cent. of driving beams had horizontal forward intensities of less than 5000 cd.

(viii) The commoner faults in headlamps were improper focusing or fitting of bulbs, failure of dipping systems, and reflectors in poor condition.

These results clearly indicate that the standard of aiming of headlamps and passlamps is very poor, and that many lamps do not provide an adequate driving light.

Acknowledgments

The work described in this paper forms part of a programme of research on vehicle lighting being carried out at the Road Research Laboratory of the Department of Scientific and Industrial Research. The paper is published by permission of the Director of Road Research.

The Laboratory is indebted to the Chief Constable of Oxford County Constabulary, without whose willing co-operation the tests would not have been possible.

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